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Viscosity Measurement of Liquid and Nematic Liquid Crystal Using Shear Horizontal Wave

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1. Introduction

Microsensors utilizing acoustic devices have attracted much attention for application in liquid environments. In the acoustic wave device for liquid sensing, energy loss into a liquid layer must be low. A shear horizontal (SH) wave, which is one of the ultrasonic shear waves, has a low propagation loss at a solid/liquid interface and is of particular interest in the case of liquid phase application. Realization of the viscosity sensor requires a small amount of the liquid sample. The use of a sandwiched construction composed of the liquid layer between two solids is an effective method to maintain or adjust the thickness of the liquid sample.

In this study, the use of a SH wave propagating in a trilayer structure composed of a viscous liquid or nematic liquid crystal layer sandwiched between two glass substrates for liquid or liquid crystal viscosity measurement is described on the basis of numerical and experimental investigations. And the dynamic viscosity change measurement of liquid and liquid crystal is also discussed.

2. Experimental

Figure 1 shows a schematic construction of SH wave device used in this study. Two interdigital transducers (IDTs) with the interdigital periodicity of 400 μm, on two 1 mm-thick piezoelectric

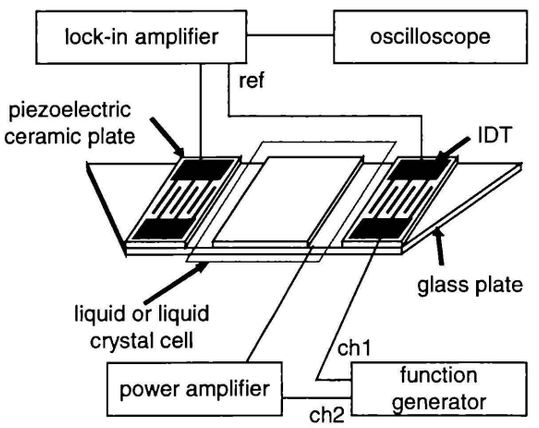

Fig. 1. Experimental setup used in this study.

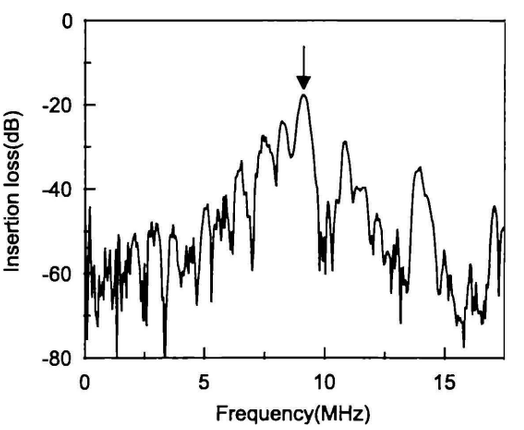

Fig. 2. Measured frequency dependence of insertion loss between two IDTs.

ceramic plates (TDK, 101A) with their poling axis in the horizontal direction, were cemented at both ends on the upper surface of a 400 μm-thick glass plate (Corning, 7059). One IDT, which was connected to a function generator (Tektronix, AFG320), was used for exciting the SH wave. And the other IDT, which was connected to a RF lock-in amplifier (Stanford Research Systems, SR844), was for receiving. A liquid or liquid crystal layer was sandwiched by two indium-tin-oxide coated glass plates. The thickness of the liquid or liquid crystal layer was 25 μm, which was adjusted using a polyethyleneterephthtalate film. In the SH wave device using the liquid crystal measurement, the surfaces of the glass plates were coated with polyimide (JSR, AL1254) and rubbed in one direction for unidirectional alignment of the liquid crystal molecule. The applied voltage to the liquid crystal layer was rectangular voltage with the frequency of 2 kHz using a function generator (Tektronix, AFG320) and a power amplifier (NF, 4010). The phase delay of the SH wave device was detected by the RF lock-in amplifier. A digital storage oscilloscope (Tektronix, TDS5052) was connected to the RF lock-in amplifier for measuring the dynamic response of the phase delay change.

3. Result and Discussion

Figure 2 shows the measured frequency dependence of insertion loss of the SH wave device. Several peaks are observed in this figure. In this study, we use the 1st mode SH wave with the frequency of 9 MHz, which corresponds to the peak of the insertion loss profile, as shown in Fig. 2. Figure 3 shows the measured phase delay change of the SH wave as a function of the square root of the liquid viscosity filling the water solutions of the glycerin in various concentrations. The phase delay change increased with the viscosity of the liquid. The phase delay change $\Delta\phi$ is related to the following the equation.

$$\Delta\phi = 360\times f\times L\times\left(\frac{1}{v}-\frac{1}{v_{ref}}\right) \qquad (1)$$

where v and v_{ref} are the phase velocities of the SH wave with and without the liquid, respectively.

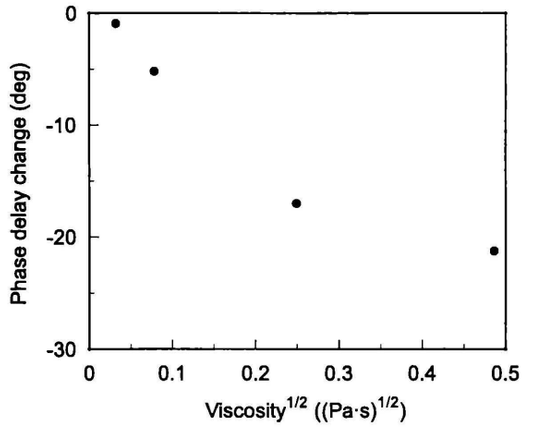

Fig. 3. Measured acoustic phase delay change of SH wave as a function of square root of viscosity in water solutions of glycerol.

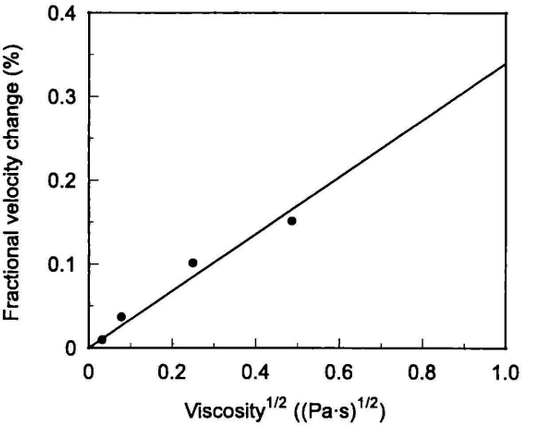

Fig. 4. Measured and calculated fractional velocity changes as a function of square root of viscosity in water solutions of glycerol.

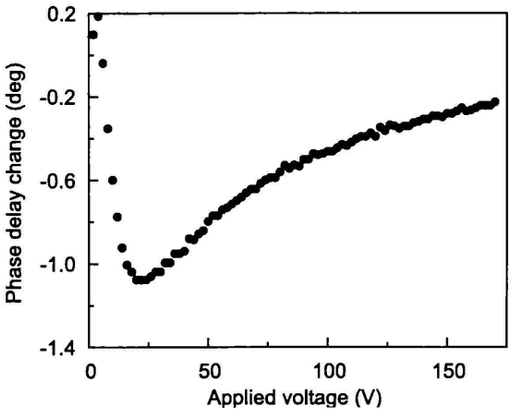

Fig. 5. Measured applied voltage dependence of acoustic phase delay change of SH wave propagating in the liquid crystal cell.

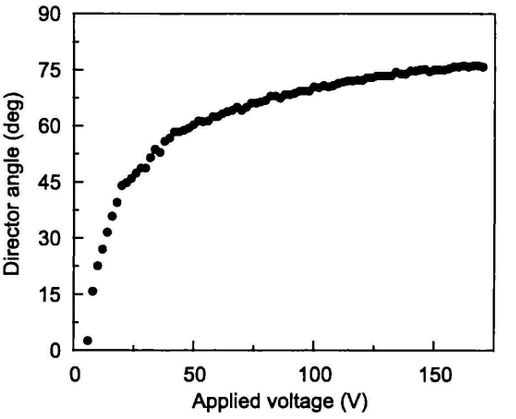

Fig. 6. Evaluated applied voltage dependence of director angle.

L is the acoustic path length which correspond to the liquid cell length, and f is the operating frequency of the SH wave device. Figure 4 shows the measured and theoretical fractional velocity changes with the square root of the liquid viscosity. Measured fractional velocity change values show linear relationship with the square root of the liquid viscosity and are consistent with the theoretical result.

Figure 5 shows the measured acoustic phase delay changes between two IDTs as a function of the applied voltage. The acoustic phase delay decreased under the low voltage application and then increased with the voltage via the bottom value. The fractional velocity change could be calculated from the measured acoustic phase delay change by Eq. (1). And the director angle of the nematic liquid crystal molecule was related to the fractional velocity change. So, the director angle can be evaluated from the measured result of the acoustic phase delay change. Figure 6 shows the evaluated applied voltage dependence of the director angle. The director angle increased with applied voltage and was saturated at about 75 degrees. The evaluated director angle is regarded as the average angle of the directors existing in the region from the interface tot the depth of a few micrometers, which corresponds to the penetration depth of the SH wave in the liquid crystal layer.

Figure 7 shows the measured time response of the director angle in the presence or absence of 50 V applied to the liquid crystal layer. This time response corresponds to the director motion of the liquid crystal molecules in the vicinity of the interface with the glass plate. The response times, accompanying the voltage application and removal, are denoted as the rise time and decay time, respectively. Figure 8 shows the applied voltage dependences of the rise time and decay time of the director angle measured using the RF lock-in amplifier and the digital storage oscilloscope. The rise time decreased with increasing the applied voltage below 50 V and converged at around 0.3 ms beyond 50 V. The minimum time constant of the lock-in amplifier used in this study is 0.1 ms and we could not measure the response time below 0.3 ms. On the other hand, the decay time is

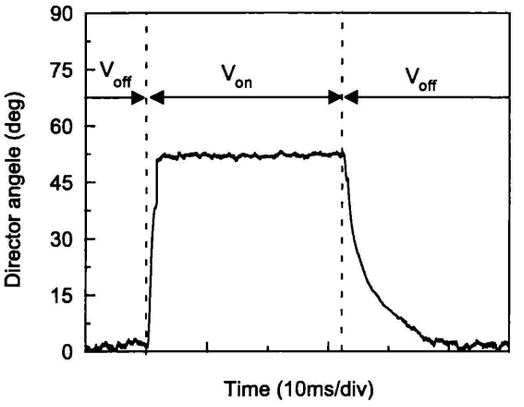

Fig. 7. Response waveform of director angle calculated from measured acoustic phase delay of SH wave in the presence or absence of applied voltage.

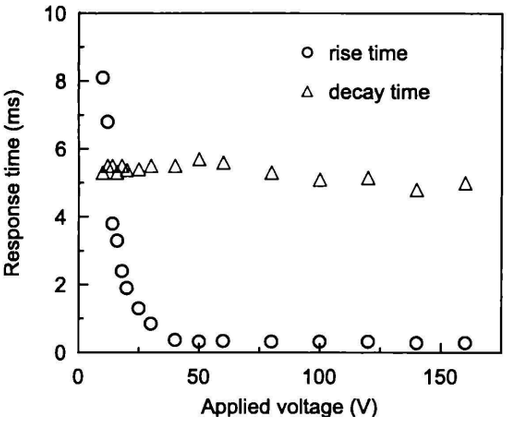

Fig. 8. Applied voltage dependences of rise and decay times of director angle response in the presence or absence of applied voltage.

independent of the applied voltage. In this measurement, we evaluated director angle utilizing the viscosity anisotropy of the nematic liquid crystal molecule. Therefore, we confirmed that the dynamic viscosity change of the liquid and liquid crystal above 0.3 ms could be measured by means of the present technique using the propagation velocity change of the SH wave.

4. Conclusion

The liquid and liquid crystal viscosity was measured in relation to the acoustic phase delay change of a SH wave propagating in a cell structure. The phase velocities of the SH wave is related to the liquid and liquid crystal viscosity. The measured result for water solutions of glycerol shows linear dependences of the fractional velocity change on the square root of liquid viscosity, which is consistent with the theoretical values. The nematic liquid crystal director reorientation to the applied voltage was evaluated utilizing anisotropy of the viscosity of the liquid crystal molecule. The dynamic viscosity change of the liquid above 0.3 ms could be measured by means the present technique.

References

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